

KPC**QASR COMPRESSION STATION PROJECT
PROCEDURE FOR SIL ALLOCATION STUDY**

					
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REV	DATE	DESCRIPTION	BY	CH'D	APP'D

	KPC Western Desert - EGYPT QASR COMPRESSION STATION PROJECT SIL ALLOCATION STUDY	
Project n° 3538-200	DOCUMENT TITLE: PROCEDURE FOR SILAllocation STUDY DOCUMENT NUMBER: 13182I-002	Rev. No.: 0 July 2013

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1 INTRODUCTION

1.1 General project description

Q SAR is a large, normally pressured gas-condensate reservoir located in the Western Desert of Egypt approximately 525 km west of Cairo. The field is operated by Khalda Petroleum Company (KPC), a joint venture between Apache Corporation and Egyptian General Petroleum Company (EGPC).

Field production is initially handled at the Start of Line (SOL) Qasr Plant. After initial treatment (cooling and water removal) the gas/condensate is exported to a combination of the Salam, Tarek and Obaiyed gas plants for further treatment. The Qasr gas and condensate currently free flows from the wellheads through the Qasr Phase I and Phase II facilities and export pipelines to the SHAMS manifold and Salam gas plant under reservoir pressure. As the reservoir pressure declines the peak gas rate of 800 mmscfd will no longer be achievable. The Q SAR Compression Project is designed to improve recovery as the reservoir production rate and pressure decline. The Qasr Compression Project scope comprises:

- Gas turbine driven single stage compressor sets
- Condensate export pumps
- Utility systems

1.2 Scope

This procedure defines modalities and methodologies to be followed in developing the SIL Allocation Study for the QASR Compression Project.

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1.3 List of definitions and abbreviations

1.3.1 Definitions

Company	KPC
Project	QASR Compression
Contractor	ENPPI
Consultant	The party which will perform the study (ICARO)
Basic Process Control System	The system that responds to input signals from the process and generates output signals to maintain operation of the process in a desired state. The system does not perform functions assessed as SIL 1 or higher.
Beta Factor	The number of Common Mode Failures (of robust Initiators or Final Elements), expressed as a fraction of all possible Failures.
Common Mode Failure	A Failure having the potential to affect all duplicated components in a robust configuration by virtue of common or shared characteristics.
Dangerous Failure	A Failure that has the potential to place the SIF in a state in which it will fail to perform its function. Dangerous Failures are usually only safe when the system has to perform a certain action or through testing. Also known as unrevealed failure.
Dangerous Failure Rate	The number of Dangerous Failures per unit time.
Demand Rate	The frequency at which a Demand occurs, i.e., the number of Demands per unit time.
Diagnostic Coverage Factor	The number of Dangerous Failures that diagnostic features are capable of detecting, expressed as a fraction of all possible dangerous failures. (NOTE: Diagnostic features may only be recognised as such if they can trip the process to a safe state or maintain safety by different means.)
Design Intent	Protective action of the Safety Instrumented Function
Failure	An abnormal condition that may cause a reduction or loss of capability of the SIF to perform its intended function.

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Final Element	A device, or combination of devices, that manipulate a process variable or attract the attention of the operator to achieve risk reduction. The Final Element includes output cards or output relays, solenoid valves and cabling. Examples are valves, switchgear (rotating equipment stop circuits) and alarms.
Hazard or Hazardous Situation	A situation with the potential to cause harm, including ill health and injury, damage to property, products or the environment, production losses or increased liabilities.
Initiator	A device, or combination of devices, that indicates whether a process or equipment item is operating outside the operating envelope. In IEC 61508/61511 an Initiator is referred to as a Sensor.
Independent Protection Layer	Device, system, or action that is capable of preventing a postulated accident sequence from proceeding to a defined, undesirable endpoint. An IPL is (1) independent of the event that initiated the accident sequence and (2) independent of any other IPLs. IPLs are normally identified during layer of protection analyses.
Intermediate Event Likelihood	Frequency of the undesired event before the mitigating factor provided the the SIF
Logic Solver	The portion of a SIF that performs the application logic function. The Logic Solver excludes trip amplifiers, input cards and output cards. Examples are electromechanical relays, solid-state/magnetic-core logic and the CPU section of programmable electronic systems.
Mitigation	The action of making a consequence less severe or relieving consequences.
Probability of Failure on Demand	The probability (dimensionless) of the SIF failing to respond to a Demand.
Programmable electronics	Electronic component or device forming part of a PES and based on computer technology. The term encompasses both hardware and software and input and output units. (Examples of process sector programmable electronics include: smart sensors; final elements; and programmable electronic logic solvers, such as, programmable controllers, PLCs, DCS, loop controllers.)
Proof Test	A test carried out on SIF components against an approved procedure to confirm that all requirements of the SIF are met.
Risk	The frequency at which a Hazardous Situation occurs multiplied by the consequence of the Hazardous Situation.
Safe Failure	A Failure whose occurrence does not have the potential to place a SIF in a dangerous state. Also known as revealed failure.

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Safety Instrumented Function	A function comprising one or more Initiators, a Logic Solver and one or more Final Elements whose purpose is to prevent or mitigate hazardous situations. A SIF is intended to achieve or maintain a safe state for the process, in respect of a specific hazardous event.
Safety Integrity Level	Dangerous failure class 1, 2, 3 or 4 derived from the consequences of failure on demand and the frequency of demand. The definition in IEC 61511: discrete level (one out of four) for specifying the safety integrity requirements of the SIF to be allocated to the SIS (trip systems). Safety integrity level 4 has the highest level of safety integrity; safety integrity level 1 has the lowest.
Target Mitigated Event Likelihood	Maximum acceptable frequency for specified severity of consequence of the undesired event
Time Risk	The fraction of overall year time during which the SIF is asked to be active. Normally for continuous operating unit, Time risk is set to 1; for intermittent process, Time risk is set to a fraction value.
Trip	An SIF action to bring the Final Element to a safe state.
Validation	Confirmation that the system under consideration fully meets the integrity requirements set forth in the associated SIF Requirements Specification.
Verification	Demonstration for a particular life-cycle phase that all deliverables (documents, software, hardware) meet the objectives set for that phase.

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1.3.2 Abbreviations

AIL	Assets Integrity Level
BDV	Blow-Down Valve
BPCS	Basic Process Control System
C&ED	Cause and Effects Diagram
DCS	Distributed Control System
ESD	Emergency Shut Down
F&G	Fire and Gas
HAZOP	Hazard and operability study
IE	Initiating Event
IEC	International Electro technical Commission
IEL	Intermediate Event Likelihood
IPL	Independent Protection Layer
LOPA	Level Of Protection Analysis
P&ID	Piping and Instrumentation Diagram
PES	Programmable Electronic System
PLC	Programmable Logic Controller
PFD	Probability of Failure on Demand
PSV	Pressure Safety Valve
ESDV	Emergency Shut Down Valve
SIF	Safety Instrumented Function
SIL	Safety integrity Level
TMEL	Target Mitigated Event Likelihood

1.4 References

- o IEC 61508-2008 “ Functional safety of electrical/electronic/programmable electronic safety-related systems”.
- o IEC 61511-2003 “ Functional safety – Safety instrumented systems for the process industry sector.

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2 SIL ALLOCATION PURPOSE AND GENERAL DESCRIPTION

2.1 SIL Allocation purpose and main topics

A Safety Integrity Level (SIL) analysis is a key step in the Safety System Design Process. While the HAZOP process normally discovers potential hazards and provides general recommendations, the SIL is a specific analysis which defines the Safety Criteria and Mitigation of hazards which can lead to a significant safety, environmental and economic consequences.

SIL analysis is performed according to the IEC 61508 ¹ extensive standard, which is essentially a framework for implementing instrumented safety systems using the principle of Safety Life Cycle, and the IEC 61511 ², developed as a Process Sector implementation of IEC 61508.

An important concept in the standard is that of the Safety Instrumented Function (SIF), which is a function to be implemented by an Safety Instrumented System (SIS) composed mainly by sensors (e.g. transmitters), logic solvers (E/E/PE) and final elements (e.g. solenoids), which is intended to achieve or maintain a safe state for the process, with respect to a specific hazardous event.

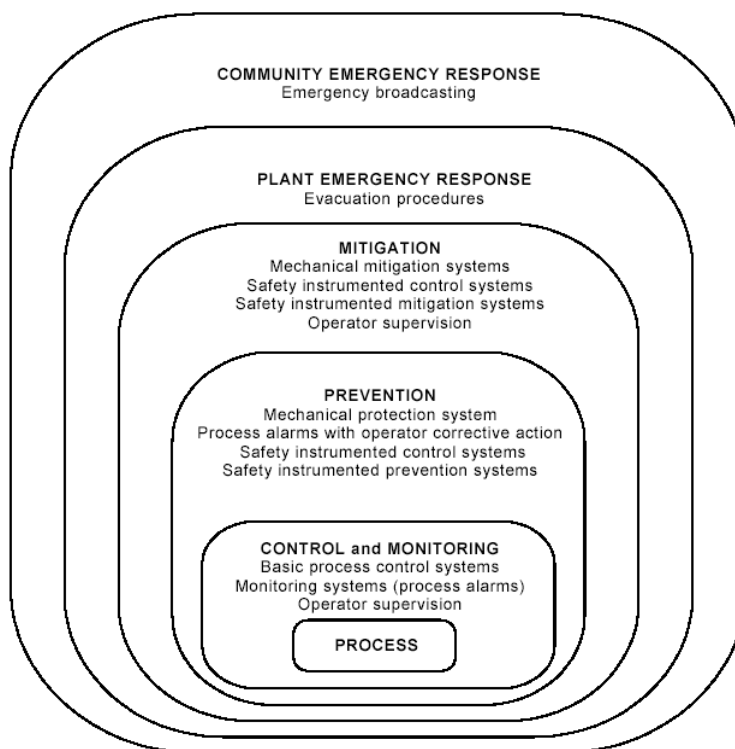
A SIS can be seen as a method to reduce the overall risk, acting as independent protection layer, as showed in figure 1.

¹ Functional safety of electrical/electronic/programmable electronic safety-related systems

² Functional safety – Safety instrumented systems for the process industry sector

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Figure 1. : Layer of protection in risk analysis



From this point of view, an independent protection layer is a “system” fully independent from the others capable to reduce the risk, by preventive or protective actions, e.g. an explosion proof design, a PSV, an independent SIF, a F&G system, an emergency procedure, etc.

Each key SIF must be evaluated for the severity of the protected risk and the performance of the SIF must be commensurate with the risk. The performance level for each SIF must address both the reliability and availability requirements of the SIF. Both of these factors are combined into a single index termed SIL, which is defined as the likelihood of the system satisfactorily performing the required safety function under all the stated conditions within a stated period of time. The SIL ratings can be equated to the Probability to Fail on Demand (PFD), in a defined interval of time, of the relevant SIF. Relationship between SIL and Process Failure on Demand is indicated in Table 1 in case of Shut Down Systems (not continuously operating systems ³).

³ Low Demand Mode: where frequency of demands for operation made on a safety-related system is no greater than one per year and no greater than twice the proof-test frequency (IEC 61508-4)

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Safety Integrity Level (SIL)	Probability of failure on demand (PFD)
4	$10^{-5} - 10^{-4}$
3	$10^{-4} - 10^{-3}$
2	$10^{-3} - 10^{-2}$
1	$10^{-2} - 10^{-1}$

Table 1. – Relationship between SIL and Process Failure on Demand

Same criteria apply also for the identification of the Asset Integrity Level of the plant/station. The analysis is to be done separately due to fact that productive asset is mainly linked to economic aspects (loss of production, loss of materials, etc.) and not necessarily linked with safety. Combined but distinct analysis allows to have a more complete picture of the risk and mostly to select the most appropriate level of protection.

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3 METHODOLOGY

3.1 Layer of Protection Analysis

LOPA is a method for evaluating the effectiveness of protection layers in reducing the frequency and/or consequence severity of hazardous events. LOPA provides specific criteria and restrictions for evaluation of IPLs, reducing subjectivity of qualitative methods.

As shown in previous Figure 1, a scenario may have one or more protection layers of various types, depending on complexity of process and potential severity of consequence.

3.2 Independent Protection Layer identification

IPLs shall be identified and selected according to the following criteria:

1. Specificity: IPL is designed to prevent a postulated accident sequence from proceeding to a defined, undesirable endpoint (e.g., runaway reaction, release of toxic material, loss of contaminant, or fire). Multiple initiating causes may lead to same hazardous event, and therefore, multiple event scenarios may initiate action of one IPL. If an event can be initiated by different initiating causes, different IPLs can apply to the different initiating causes.
2. Independence: IPL is independent of all other protection layers associated with identified potentially hazardous event. Independence requires that performance not be affected by failure of another protection layer or by conditions that caused another protection layer to fail. Protection layer are also independent of initiating cause.
3. Dependability: Protection provided by IPL reduces identified risk by known and specified amount.
4. Auditability: IPL is designed to enable periodic validation of protective function. Periodic testing and maintenance of IPL is required.

3.3 SIL Assessment approach

SIL assessment is based on application of LOPA on the results of the HAZOP study. The basic procedure is detailed herebelow.

1. Each SIF is analyzed with reference to the consequences undesired event of HAZOP deviation for which the SIF itself has been claimed as Safeguard measure.
2. Estimate the consequences of undesired event according to the qualitative classification provided in the present procedure.
3. For each defined level of consequences (damage to people, asset and environment), a correlated **TMEL** is defined.

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4. Define, on basis of selected referenced database, the associated likelihood to the **initiating cause** of the deviation.
5. Define, on basis of selected referenced database, the **Time Risk**.
6. Identify in the process and with reference to HAZOP study the presence and effectiveness of mitigating **BPCS** and consequently assess its unavailability according to selected referenced database;
7. Identify in the process and with reference to HAZOP study, the presence and effectiveness of **alarm** that might give to operator the possibility of safe and timely mitigating action and consequently assess its unavailability according to selected referenced database.
8. Estimate the probabilistic value of **vulnerability** of exposed persons to the effects of the identified scenario.
9. Identify in the process and with reference to HAZOP study the presence and effectiveness of mitigating **IPL** and consequently assess its PFD according to selected referenced database.
10. Calculate the **IEL** as the product of initial likelihood of the initiating cause and the unavailability of each protection layer;
11. Calculate the quotient between **TMEL** and IEL and identify the required **PFD** to associated to the analyzed SIF in order to reach the expected results.
12. Proceed to the subsequent SIF and repeat passages from 2 to 11.

3.4 Consequence estimate and relevant TMEL

Following table indicates the proposed values for classification of consequences of initial causes and relevant values of TMEL to be reached in SIL assessment.

Severity Level	Health and safety consequences	Environmental effects	Asset effects	TMEL
A	Catastrophic health/safety incident causing very widespread fatalities within or outside a facility. Potential for 3 or more fatalities.	Extensive damage outside the industrial site fence to a non-sensitive environment and which remains in an "unsatisfactory" state for a period > 5 yr.	>100 million	1,00E-07
B	Catastrophic health/safety incident causing widespread fatalities within or outside a facility. Potential for 1 to 3 fatalities.	Extensive damage outside the industrial site fence to a non-sensitive environment and which can only be remediated to a "satisfactory" / agreed state in a period of 2 yr to 4 yr.	€ 20 million to € 100 million	1,00E-06

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Severity Level	Health and safety consequences	Environmental effects	Asset effects	TMEL
C	Very major health/ safety incident - Potential for 1 fatality. - 10 or more injuries or health effects to plant workforce, either permanent or requiring hospital treatment for more than 24 hr.	Extensive damage outside the industrial site fence to a non-sensitive environment and which can be remediated to a level which restores its environmental amenity in a period of 1 yr.	€10 million to €20 million	1,00E-05
D	High impact health/ safety incident - Permanent partial disability(ies) - Several non-permanent injuries or health impacts.	Significant damage outside the plant fence but within industrial site fence	€1 million to €10 million	1,00E-04
E	Medium impact health/ safety incident - Single or multiple recordable injury or health effects from common source/event.	Localized damage outside the plant fence but within industrial site fence	€500 k to €1 million	1,00E-03
F	Low impact health/ safety incident - First aid - Single or multiple over-exposures causing noticeable irritation but no actual health effects	Possible emission of gas/liquid wastes outside the plant fence but inside the site fence	€100 k to €500 k	1,00E-02
G	Negligible effects.	Increase of plant wastes (flushing, blow down)	< €100 k	1,00E-01

Table 2. – Classification of severity level of consequences and relevant TMEL to be achieved

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3.5 Likelihood for initiating causes

Following table indicates the proposed values for the likelihood of initiating causes.

Initiating Cause	Likelihood of failure (events/year)	Data Source
Pump and other rotating equipment failure	5,00E-02	Oreda 2002
BPCS instrument loop failure	1,00E-01	CCPS
Pump seal failure	1,00E-01	Oreda 2002
Spurious closure of on off valve	5,00E-02	Exida 2007
Utility unavailability (CW, N, LS, MS)	1,00E-01	CCPS
Power failure	1,00E+00	Eng. Estimate
Procedural mistake	1,00E-01	CW
Unloading/loading hose failure	1,00E-02	Eng. Estimate
Safety valve opens spuriously	1,00E-02	CCPS
Incorrect alignment (manual valve on normal operation)	1,00E-01	CW
Tube rupture in heat exchanger	5,00E-02	Eng. Estimate
Incorrect alignment (manual valve on start up / shut down)	1,00E-01	CW
External fire	1,00E-02	Eng. Estimate

Table 3. – Values of likelihood for initiating causes

3.6 Time risk

Time risk is set equal to 1 for continuous process and for discontinuous process which are working for more than 10% of overall time.

For discontinuous process which are working for less than 10% of overall time (e.g. loading from tank truck), the time risk is set equal to 0.1.

3.7 BPCS

In the case that the system is equipped with an independent process control system capable to prevent the undesired consequences, it is possible to claim a reduction factor equal to 0.1.

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3.8 Alarms

In the case that the system is equipped with a DCS alarm activated by a process upset detected by an independent measure, it is possible to claim a reduction factor.

The suggested values are the same:

- in case the alarms gives the operator more than 10 minutes to take action before the undesired event occurs: 0.1
- in case the alarms gives the operator less than 10 minutes to take action before the undesired event occurs: 0.5

3.9 Vulnerability

Vulnerability factor takes into account the probability for a person to be directly involved in the effects of undesired event. The factor shall take into consideration both the dynamics of the final scenario (e.g. fire) and the effective presence of people in the area inside which the impact from the scenario is expected. Suggested values are the following:

Jet fire/explosion in frequently manned areas:	1
Jet fire/explosion in not frequently manned areas:	0,5
Pool fire / flash fire in frequently manned areas:	0,5
Pool fire / flash fire in not frequently manned areas:	0,1

3.10 Independent Protection layers

Following table indicates the proposed values for the PFD of Level of Protection elements.

IPL	PFD	Data Source
PSV specifically designed for the scenario	1,00E-02	Oreda 2002
Rupture disk specifically designed for the scenario	1,00E-02	Oreda 2002
BPCS	1,00E-01	CCPS
Dike, bund	1,00E-01	Eng. Estimate
Sewer system	1,00E-01	Eng. Estimate

Table 4. – PFD for different level of protection elements

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3.11 Reference for the selected probability values

- o **CW:** Cremer & Warner - App IX in COVO Commission- “Risk analysis of six potentially hazardous industrial objects in the Rijnmond Area, a pilot study – A report to the Rijnmond Public Authority”, 1981
- o **CCPS:** Process Equipment reliability data base, Center for Chemical Process Safety, 1989
- o **Oreda 2002:** Offshore Reliability Data Handbook, OREDA – 4th Edition, 2002
- o **Exida 2007:** Safety Equipment Reliability Handbook, Exida – 3rd Edition, 2007

3.12 SIL Allocation report

- Scope of the study;
- Process descriptions;
- Methodology description;
- Table of deviations;
- Attendance list;
- Nodes list;
- Reference documentation;
- C&EDs used for the sessions (“master copies”);
- SIL Allocation worksheets;
- Recommendations (actions) lists.

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4 WORKING DOCUMENTATION

4.1 Basic documents

Following is a list of documentation strictly necessary for the development of the SIL Allocation study.

N	Document	Delivery time limits
1	Process and Utilities Basis of Design	One week before SIL Allocation session
2	Process Flow Diagram - PFD	As above
3	Utility Flow Diagram - UFD	As above
4	Project P&ID	As above
5	Booster Compressor P&ID	As above
6	Plot Plan	As above
7	Cause And Effect Diagram	As above
8	Control, Shutdown And Process Safeguarding Philosophy (ESD Philosophy)	As above
9	Blow down, Flaring and Venting Philosophy	As above

4.2 Supplementary documents

The following documents shall be available in case of need:

- MSDS (Material Safety Data Sheets) of dangerous substances;
- Project Safety Philosophy document;
- Emergency system design philosophy;
- Detailed thematic plot plans, e.g. active fire systems, smoke/fire/gas detectors location, sewer networks, etc.
- Operating, maintenance and emergency procedures /manuals, if available.

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5 SIL ALLOCATION TEAM

The SIL sessions, shall include following experts:

- SIL facilitator (ICARO);
- SIL Secretary (ENPPI or ICARO);
- Lead HSE Engineer;
- Lead Process Engineer;
- Instrument Engineer (on call);
- Process Engineer (Company);
- Process/Operation specialist (Owner);
- Mechanical / maintenance Engineer (on call).

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6 SIL ALLOCATION PROGRAMME AND SCHEDULING

6.1 Nodes identification

Before starting SIL Allocation session, the selected SIFs will be inputted in the SIL Allocation.

6.2 Logistics

For successful development of HAZOP / SIL analysis sessions, the availability of a dedicated meeting room of suitable dimensions and windows, with large table and a video projection system for showing to all participants the worksheets in progress, is strongly required.

It is also recommendable the availability of a suitable number of copies of C&EDs and P&IDs to be distributed to each participant (also in A3 format) plus one copy (in original size) to be used as Master Copy of the session.

SIL Allocation meeting is normally scheduled with two distinct sessions (morning and afternoon) of maximum three hours each with suitable breaks.

6.3 Scheduling

According to preliminary documentation provided, the estimated duration of SIL Allocation session is 3 days.

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ANNEX 1 – SIL ALLOCATION WORKSHEET

Interlock		I-0115		Design Intent			Protection of V-01 against overfilling							
Initiators		LAZHH010		P&ID			PID-0001-000		Final elements			ESDV001		
Remarks														
Ref.	1	2		3		4	5	6	7	8	9	10	11	
	Impact event description	Impact level	TMEL (occ./year)	#	Cause	Initiation likelihood (occ./year)	Time risk	BPCS	Alarms	Vulnerability (health)	Additional IPL	Intermediate Event mitigated likelihood	SIF integrity level	SIL
1	Overfilling of V-01 leading to liquid carry and consequent overpressurization			a	Failure open of LV012	0,1	1	0,1	0,1	0,1	1	1,00E-04		
				b								0,00E+00		
				c								0,00E+00		
				d								0,00E+00		
				e								0,00E+00		
	HEALTH	B	1,00E-06									1,00E-04	1,00E-02	1
	ENVIRONMENTAL	C	1,00E-05									1,00E-03	1,00E-02	1
	ASSET	C	1,00E-05									1,00E-03	1,00E-02	1